Geoacoustic Inversion for Spatially and Temporally Varying Shallow Water Environments

ONR Special Research Awards in Underwater Acoustics:
Entry Level Faculty Award

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LONG-TERM OBJECTIVES

The long-term objective of this proposal is to develop methods for rapid assessment of seabed variability combined with detailed localized geoacoustic inversions to characterize the bottom for a given shallow-water environment. Consideration will be given to spatial and temporal variability in the watercolumn properties common to shallow-water environments and their impact on inversion results. Methods will be developed in recognition of Navy needs for Rapid Environmental Assessment (REA) in littoral regions and corresponding interests in Intelligence, Surveillance, and Reconnaissance (ISR), Anti-Submarine Warfare (ASW), and Mine Warfare (MIW).

GOALS OF THE PRESENT PROPOSAL

The goals of this proposed project are to develop improved methods for extracting physical seabed parameters in shallow water. Methods will be developed using modal content and dispersion of acoustic fields to determine range dependence in the sediment structure and to construct background models for either linear (perturbative) or non-linear geoacoustic inversion methods such as those based on genetic algorithms (GA) or simulated annealing (SA).

APPROACH

The approach will be based on the analysis of both simulated and measured data representing a variety of geoacoustic environments. Emphasis will be placed on parameter extraction for environments with spatially varying sediment properties using both broadband and cw data spanning 50-500 Hz. The work is motivation by past work in geacoustic inversion using horizontal array data [R1][R2], the 2001 Geoacoustic Inversion Techniques Workshop (GAIT) sponsored by ONR and SPAWAR [R3], and the 2006 shallow-water experiments (SW06) taking place on the NJ shelf[R4]. The goal of this work is to infer range-dependent bottom properties in shallow-water waveguides. The emphasis is on linearized inverse methods using the modal content of propagating acoustic fields as input data to the inversion algorithms. To further refine the parameter estimates, the efficiency of using the low-resolution range-dependent results as an initial parameterization of higher-resolution global search algorithms will be examined.

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14. ABSTRACT
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The proposed work will seek to find a solution to geoacoustic inversion problem which is optimized for both efficiency and accuracy. Emphasis will be placed on developing a method that is capable of accounting for range-dependence in the seabed that is both measurable, such as bathymetry, and unknown, such as that due to intrusions or layer pinching. Specific research areas for this approach include continued investigation of high-resolution wavenumber [R5-3] and modal estimation techniques, addressing the impact of watercolumn variability on wavenumber estimation [R6][R7], and exploring new methods for removing the effects of bathymetry on the measured acoustic fields, as in [R8-5]. In addition to an approach based on modal wavenumbers, inversion methods based on modal dispersion will also be explored. Modal dispersion will be examined for both broadband pulses and for a comb of cw tones for moving sources[R9,6]. Modal dispersion in the latter case was observed for 50 Hz data during the October 2000 Shallow Water Acoustic Technology (SWAT) experiments (Chief Scientist Robert Field, NRL). Based on the observations, a method was devised for inferring modal group velocities from measurements of the shift in horizontal wavenumbers for a moving source[R10,3]. Further validation of the method is sought through the design and implementation of experiments for SW06.

The proposed work will make use of both existing and future measured data sets. The benchmark data set from the Geoacoustic Inversion Techniques Workshop [R3] provides both horizontal and vertical array data that can be used in developing and testing a hybrid geoacoustic inversion method. An effort has begun with collaborators from University of Deleware (M. Badiey) and University of Rhode Island (G. Potty) examining data collected during the SWARM experiment in 1995. New methods could be applied to select data sets acquired during SWAT and other recent shallow water experiments. Also of interest would be analysis of towed CTD chain data acquired during the Geoclutter 2003. This data set provides measurements of the temporal/spatial variability in the watercolumn on the NJ Shelf over the course of the Geoclutter experiment. This data would help to support analysis of the acoustic measurements, and also provide realistic environmental input data for modeling efforts to understanding the impact of watercolumn variability on acoustic measurements and inversion results.

As part of this work, experimental methods will be designed to gather data in order to validate the new inversion methods. Experimental plans have been provided for consideration in the upcoming ONR shallow-water acoustics experiment in 2006 (SW06). The experiments suggested were designed with much flexibility in anticipation of using assets already being deployed or operated by other experiment participants.

WORK COMPLETED

This report comes 8 months into a 3 year program focused on geoacoustic inverse methods. As such, the emphasis to this point has been on laying the groundwork for an experimental program starting in 2006. In particular, in preparation for SW06 it was necessary to line up potential collaborators and equipment to achieve the intended objectives of this work. Working with colleagues from the Woods Hole Oceanographic Institution (WHOI – J. Lynch) and The University of Delaware (UDel – M. Badiey) the required acoustic sources and receivers have been identified along with a plan for operation and data sharing. In addition, working with colleagues from The University of Washington (UW – F. Henyey and D. Tang) a plan has been made to incorporate the use of a towed CTD chain in the experimental work. To date, a detailed cruise plan has been worked out and submitted to the chief scientists organizing SW06 [R11]. Additionally, a student in the Graduate Program in Acoustics

(Megan S. DeWitt) has begun work with me on this project. Megan is funded internally by the Applied Research Laboratory and will participate in next years cruise.

Related to the above, UW purchased 32 new CTD sensors for the towed CTD chain. Working with a graduate student from Penn State (Joy E. Lyons), the new sensors have been tested in the lab and incorporated into a 50 element CTD chain. The chain system has been integrated at Penn State and will be shipped to the University of Rhode Island (URI) for a check-out test the first week of October.

RESULTS

An Autoregressive spectral estimator was evaluated and its performance compared to ESPRIT for wavenumber estimation from noisy horizontal aperture acoustic data. The AR estimator performance was as good as other high-resolution methods [R12] and superior to methods based on Fast Fourier Transforms. It has the benefit of not requiring *a priori* information about the data. In addition, using a short-aperture sliding window AR transform method, the resulting range/wavenumber plots yield a robust way for determining modal wavenumber content for range-dependent waveguides. Using this approach, it was demonstrated that the higher order modes are less sensitive to water column variability. As these wavenumbers are known to be most sensitive to changes in bottom properties, this result shows promise for determining range-dependence in the waveguide. The sensitivity of wavenumber estimates for different aperture lengths for a variable water column and range-independent sediment is shown in Fig. 1.

Also, in preparation for SW06, a preliminary study of the effects of waveguide variability on synthetic aperture pressure field measurements has been started. It was recognized that that temporal and spatial fluctuations of the water column affect both the source function and received field. Fig. 2 compares sound speed variability seen by the receiver to that of the source for a 10 km separation distance. Depending on the relative motion of source and receiver to the internal waves, varying amounts of variability is observed. This is a difficult problem to model, yet important for understanding its impact on geoacoustic inversion methods, as well as source localization approaches and other techniques based on the use of freely drifting receivers such as sonobuoys.

IMPACT/APPLICATIONS

The application of these results is for geoacoustic inversion in range-dependent shallow water regions. The results suggest ways to account for and deal with the variability inherent in the watercolumn in shallow regions. In addition, the high-resolution methods reduce the apertures required to extract modal information resulting in more localized inversion results.

RELATED PROJECTS

This work is closely related to the goals and objectives of the upcoming shallow-water experiment in 2006. The approaches being developed recognize the complexities of shallow water waveguide environments and seek to account for them. In addition, plans have been developed for co-located experiments that will allow direct comparison of results from other PIs.

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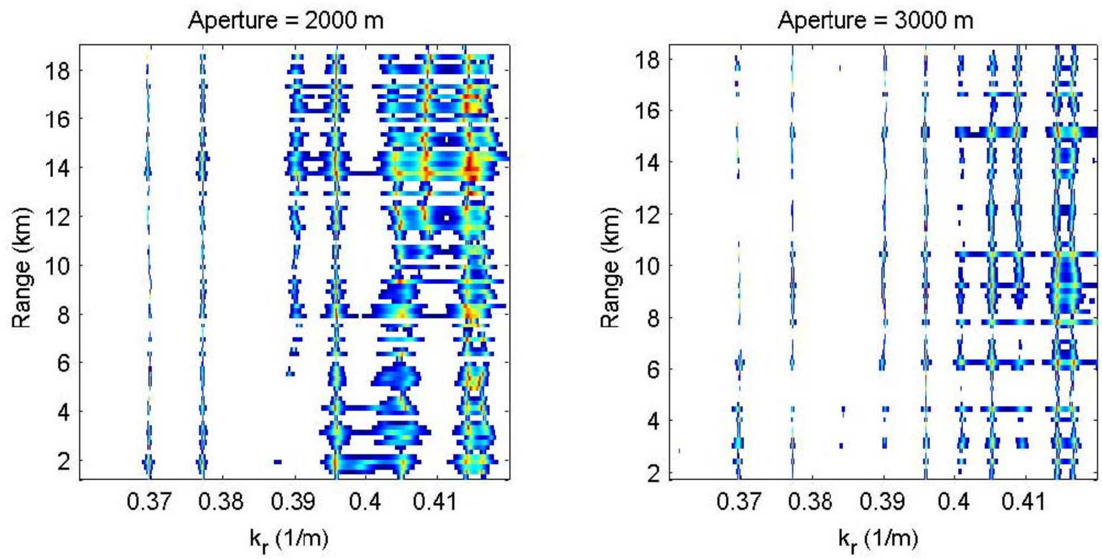

Fig. 1 Range/wavenumber estimates in shallow-water including internal waves in the water column. High order modes show low sensitivity to effects of IW field.

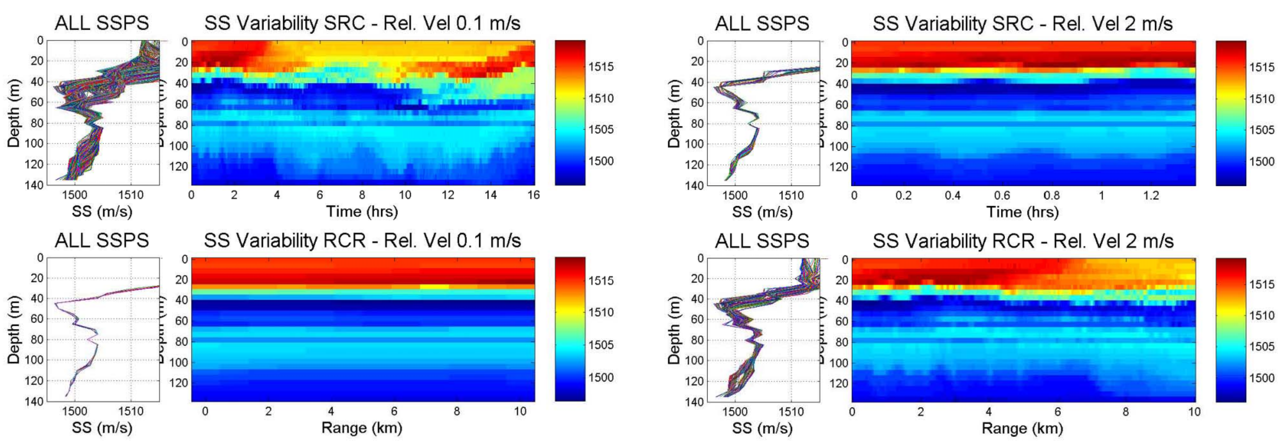

Fig 2. Effect of IW field on Synthetic Aperture acoustics measurements - Variability seen by the source vs receiver for src/rcr speed relative to IWs.